45th CIRP Conference on Manufacturing Systems 2012

Model for the Valuation of a Technology Established in a Manufacturing System

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Abstract

The valuation of technologies is necessary in many situations. These vary from investments in machinery to manufacture developed products to the selection of new production technologies to fulfil customer demands. In this paper we present the current version of the developed model for the valuation of a technology in a manufacturing system. The model focuses on technology-related objectives of the manufacturing system and the link to relevant characteristics of manufacturing technologies. The valuation model of this on-going research allows to quantify, measure and assess consequences of the application of a specific technology and its value contribution to the manufacturing system.

Keywords: Technology Valuation; Technology Assessment; Manufacturing Systems Planning; Performance Measurement

1. Introduction

In many cases, manufacturing technology is a key driver for product innovation, for cost-reduction in the production process or for fulfilment of customer demands concerning quality or sustainability. Therefore, the assessment and selection of technologies capable to manufacture the firm’s current and future products is an important process in technology management [1]. After the identification of new technologies, the assessment and selection can be supported by portfolio methods, scenario-based methods, expert judgment, pilot studies or financial methods. Within the technology assessment process, technology valuation aims at the determination of the economic value of a technology. The valuation of manufacturing technologies is often difficult, not only because the selection of one specific technology affects the whole manufacturing process chain. Moreover, the value-contribution of the technology to the manufacturing system influences the manufacturing performance. As depicted in Fig 1, on one hand technology and manufacturing strategy should be in line with the business strategy and should therefore positively influence manufacturing and business performance, respectively. One the other hand, however, business strategy has to be based on the manufacturing and technology capabilities and competencies.

![Alignment of business, manufacturing and technology strategy and influence on business performance](image-url)

Fig. 1. Alignment of business, manufacturing and technology strategy and influence on business performance
If the strategies and objectives are in alignment, a technology established in the manufacturing system can contribute to the improvement of manufacturing performance. An improved manufacturing performance in turn can positively influence the manufacturing contribution to the improvement of business performance [2].

The aforementioned hierarchical structure of strategies and performance measures implies that a manufacturing technology valuation requires an investigation of the relationship between technology characteristics and manufacturing performance measures. However, the measurement of manufacturing performance is complex due to the multi-dimensional nature of manufacturing [3].

Considering performance from a systems and technology point of view, Fig 2 shows the evolution of performance measures starting from cost-based measures in the 1960’s according to [3]. The emphasis of performance measures changed in different time periods. In the 1980’s the total productivity measures and afterwards quality measures gained importance. Starting from the 1990’s, the multi-dimensional measures, such as cost, speed, dependability, quality and flexibility were used and generally accepted as performance indicators for manufacturing systems [3].

In accordance to multi-dimensional manufacturing system performance measures, valuation of technologies also requires the consideration of multi-dimensional criteria. The presented valuation model aims at an extension of the one-dimensional financial view of existing technology valuation methods by integrating the multi-dimensional view. This would allow to determine the value-contribution of a technology established in a manufacturing system to the manufacturing performance, and hence to the business performance.

In this paper, a new model for valuing a technology established in a manufacturing system will be presented.

The paper is structured as follows. After the introduction, an overview of existing valuation approaches including their application is given in Section 2. In Section 3, the manufacturing technology valuation model is introduced. The framework for the valuation is proposed and the model assumptions are discussed. As a basis for the model, technology-related objectives of manufacturing systems are reviewed. Furthermore, limitations in current research, implications and future research issues are discussed. Finally, Section 4 includes a brief conclusion.

2. Valuation approaches: Literature overview

2.1. Valuation

Manufacturing aims at creating value. However, the nature of value comprises multiple aspects. Values resulting from general socio-cultural framework conditions or individual preferences are characteristic of something being recognized, prized, admired or sought after [4]. Whereas historically in the manufacturing environment cost issues were emphasized in evaluations [5], in manufacturing technology valuation an expansion of the traditional perspective is necessary. This is due to the fact that in technology assessment different value domains (such as functionality, economy, quality, flexibility, sustainability) have to be considered. Furthermore, the value of a technology can be expressed among others in score, index or monetary value [6].

2.2. Existing technology valuation methods and their application

The main monetary technology valuation approaches comprise (according to [7], [8], [9], [10] and [11]) discounted cash flow methods and real options approaches.

In theory, monetary value models quantify the value of any asset (e.g. a manufacturing technology) by measuring the future cash flows that it will generate, corrected for the risk of those cash flows [7]. According to the discounted cash flow (DCF) approach, the value \( V \) of a technology can be calculated as follows:

\[
V = \sum_{t=1}^{T} \frac{CF_t}{(1+k)^t}
\]  

where \( CF_t \) denotes the cash flow in period \( t \) of a series of \( T \) cash flows. The cash flows are then subject to a discount rate \( k \). Note that due to the fact that the focus lies on future cash flows, the determination of the
monetary value is difficult and many assumptions and estimates are required.

In practice, monetary technology valuation models to assess implemented manufacturing technologies and technologies that do not yet belong to the firm’s technological base, are only applied in limited cases.

3. Manufacturing technology valuation model

3.1. Objective and framework for the manufacturing technology valuation

The objective of the new manufacturing technology valuation model is to determine the value-contribution of an applied or future manufacturing technology to the manufacturing system. The model will provide methodological support when determining the influence exerted by a manufacturing technology on the value of a manufacturing system in terms of the value provided to the customer.

A key element of the valuation model is the linkage of the systems technological objectives and technology-oriented parameters via cause and effect relationships. The monetary value of the contribution made by the manufacturing technology hence can be determined on the basis of the expected discounted cash flows related to manufacturing technology deployment and the cause and effect relationships.

The basic concept of the valuation model comprises four main modules (also described in detail in [12]):

- Technology-related objectives of the manufacturing system: Derived from objectives and performance measures of the manufacturing system, technological objectives build the basis to define related cash flow categories (revenues and cost) of the monetary valuation model. Hence, manufacturing objectives and technology-related objectives are aligned and the influence of manufacturing technology on manufacturing performance and (partly) business performance can be proved, even in the case of conflicting objectives.
- Monetary valuation model: The discounted cash flow model is the basis of the proposed manufacturing technology valuation model. Due to the consideration of derived technology-related income and cost categories, it allows for a multi-criteria evaluation in terms of the technological objectives of the manufacturing system.
- Product and process-related technology description: The quantification of the value-contribution of a specific manufacturing technology requires an integrated view of the products to be manufactured and the existing processes. Therefore, a module-based technology description will be developed providing a uniform and comprehensive characterization of the technology deployed in the manufacturing system. Exemplary, different sub-modules of technology description outline technical characteristics, product-, process- and time-related characteristics as well as quality-, flexibility-, sustainability- and investment-related characteristics. Relevant characteristics have to be identified via an influence analysis on cash flow (sub-)categories.
- Cause and effect relationships: Subsequently, cause and effect relationship have to be identified and presented quantitatively in order to link technological parameters with defined cash flow (sub-) categories. On one hand, existing principles can be used for the formal description of cause and effect relationships. On the other hand, methodological approaches to determine technology-specific cost drivers and cost functions will be analyzed. Once the dependencies (‘Which parameters are dependent on which others?’) have been identified, the question ‘What is the nature of the dependencies between parameters?’ has to be answered.

The alignment of manufacturing performance and technological objectives combined with a monetary valuation model founded on product- and process-related technological characteristics and according cause and effect relationship, guarantee a consistent determination of the value-contribution of the manufacturing technology to the considered manufacturing system.

3.2. Model assumptions

General requirements concerning the valuation model comprise the following aspects (c.f. [6]): firstly, a monetary value model is desired because this implies the real meaning of economic value aspired in the manufacturing industry. The structure of the model should be easy to understand and in consequence applicable in practice. Due to the huge variety of manufacturing technologies, the model should be adaptable or extendable to technology-specific aspects, respectively. Since the manufacturing technology valuation is a difficult and complex task, the model should allow for a decomposition in distinctive modules (e.g. cash flow categories), which can be investigated separately (with regard to cause and effect relationships, technological cost drivers and parameters), depending on its impact on value.

3.3. Technology-related objectives of manufacturing systems

Following the definition by Deuermeyer, ‘a manufacturing system is an objective-oriented network of processes through which entities flow’ (c.f. [13]). The key words of the definition emphasize that a manufacturing system has objectives. According to Hopp and Spearman, the ‘increase of the well-being of stakeholders (stockholders, employees, and customers)
Table 1. Overview of manufacturing systems objectives (based on [5], [14] and [15])

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<td>Innovativeness</td>
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Table 2. Overview of manufacturing systems objectives (based on [5], [14] and [15])

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<td>Delivery reliability</td>
<td>Productivity</td>
<td>Reliability of lead or delivery time</td>
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<td>Delivery speed</td>
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<td>Demand increase</td>
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over the long term’ [13] can serve as fundamental objective for almost any manufacturing company. Since such high-level objectives are generally not measurable and the description of interactions between components and their effect on the whole system is very complex [13], various supporting subordinate and conflicting objectives have to be defined. Table 1 and Table 2 summarize objectives and performance measures of a manufacturing system which were investigated by different authors in recent years (c.f. [5], [14] and [15]). There is no consensus in literature on performance objectives of a manufacturing system. The objectives represent trade-offs [14], which have to be made in order to find the best solution with regard to the fundamental objective. Obviously, there is a need to measure the performance of a manufacturing system in terms of cost, quality, time and flexibility. According to Hon, the importance of sustainability objectives is increasing [5]. For each objective, many individual measures exist and were applied in practice for measuring a specific characteristic on manufacturing performance on different levels (such as machine, cell, line, factory or network). Whereas for cost the number of individual measures is relatively high for example due to accounting standards, there is a lack of standards for flexibility performance measurement [5].

As a basis for the valuation of a technology deployed in a manufacturing system, technology-related objectives of the manufacturing system are used as evaluation criteria. For this work, the subordinate manufacturing system objectives cost, quality, flexibility and sustainability will be used as top-level technology-related objectives in the further discussion and model development. By defining these objectives it was taken into account that the deployed manufacturing technology (technology characteristics) must have an impact on the objective, which can be described via a formal cause and effect relationship.

Time aspects are not neglected, but were subordinate due to the fact that (technological) time measures (such as primary time or secondary time, machine down time) or productivity measures (machine utilization) influence different defined top-level objectives and are often used to derive related measures (e.g. manufacturing costs or delivery flexibility).

3.4. The new valuation model

In technology management, producing companies have to choose manufacturing technologies to produce current and future products. Thereby, technology managers need to link technology with business needs [16]. According to the fundamental manufacturing systems objective, it is necessary to determine the value-contribution of a manufacturing technology to the system in order to identify the technology with the highest impact on manufacturing and hence business performance. This is done by considering the value associated with a manufacturing technology. The derived technology-related objectives of the manufacturing system can serve as evaluation criteria. Consequently, it is possible to choose relevant criteria and include those in the model.

Based on the technology-related manufacturing objectives, the expected discounted cash flow model to determine the manufacturing technology value $MTV$ can be described by the formula

$$MTV = \sum_{t=0}^{T} \frac{ECF_t}{(1 + WACC)^t}$$

where $ECF_t$ denotes the expected cash flow associated to the manufacturing technology in time period $t$, $T$ denotes the end of the evaluation phase (use of the manufacturing technology) and $WACC$ the
weighted average cost of capital. For each time period, one has to subtract objective-oriented (anticipated) costs from the expected revenues $r$:

$$ECF = r - \left( c_M + c_Q + c_F + c_S + cc + \delta \right).$$

Here, costs are derived by adding the manufacturing cost $c_M$, quality cost $c_Q$, flexibility cost $c_F$, sustainability cost $c_S$, capital cost $cc$ and capital depreciation $\delta$. In the following, the manufacturing technology-related revenues and expenditures are considered and their measurement is discussed.

**Technology-related revenues**

Although customers generally purchase products and features rather than technologies, manufacturing technologies exert considerable influence on customer’s benefit, differentiation and functions of products. Thus, technology-related revenues arise from selling manufactured products. According to Haag [11], the bundle of services of each product manufactured with the manufacturing technology under investigation has to be decomposed in order to analyse the impact of the technology on specific product utilities. Hence, it’s necessary to model the technology impact on the product(s). The decomposition of product(s) in functions and assignment of the manufacturing technology allows to evaluate the (additional) utility due to the technology (compared to the status when the technology would not be used to manufacture the product(s)). To determine the technology impact on the utility of a product quantitatively, conjoint analysis, expert judgement or linear performance pricing (LPP)-method can be applied [11]. Using the derived utility contribution of the technology, it is possible to calculate expected revenues based on a market analysis and scenarios on the selling of product(s) and associated prices. Since a flexible manufacturing technology can be utilised to produce various products, the described procedure has to take into account all products manufactured with the considered technology.

**Technology-related cost**

As shown in Formula 3, the technology-related cost factors have been divided into the categories manufacturing cost $c_M$, quality cost $c_Q$, flexibility cost $c_F$, sustainability cost $c_S$, capital cost $cc$ and capital depreciation $\delta$. Within each category, sub-categories have to be defined and linked with technology characteristics and parameters as depicted exemplary in Fig 3. As it is not feasible to include all cost parameters in this paper, representative costs are given for each category as follows:

- Manufacturing cost $c_M$: material cost, maintenance cost, setup cost, unit labor cost, …
- Quality cost $c_Q$: prevention cost, appraisal cost, internal failure cost, external failure cost, …
- Flexibility cost $c_F$: machine flexibility, material handling flexibility, volume flexibility, …
- Sustainability cost $c_S$: energy consumption, water use, waste generation, …
- Capital cost $cc$: interests payments, investment expenditure, risk, …
- Capital depreciation $\delta$: decrease in value of the investment, capital depreciation resulting from rigors of manufacturing

After defining cost factors, costs have to be linked with technology characteristics as exemplary shown in Fig 3 and cause and effect-relationship have to be determined.

**3.5. Future research**

Within this on-going research, further work that is needed to improve and to detail the introduced manufacturing technology valuation model includes developing and extending the current model: besides the determination of the technology-related revenues, the cost categories have to be detailed. Sub-categories have to be defined in order to structure the valuation. Due to the nature of flexibility, many different measurement

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**Fig. 3.** Linking technology-related manufacturing objectives, associated cost and technology characteristics

- Flexibility cost $c_F$: machine flexibility, material handling flexibility, volume flexibility, …
- Sustainability cost $c_S$: energy consumption, water use, waste generation, …
- Capital cost $cc$: interests payments, investment expenditure, risk, …
- Capital depreciation $\delta$: decrease in value of the investment, capital depreciation resulting from rigors of manufacturing

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**Table:** Technology-related objectives

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<tr>
<th>Technology-related objectives</th>
<th>Product-related objectives</th>
<th>Process-related objectives</th>
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<tr>
<td>$r$</td>
<td>$c_M$</td>
<td>$c_Q$</td>
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<tr>
<td>$c_F$</td>
<td></td>
<td>Preventive cost</td>
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<td>$c_S$</td>
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<td>Appraisal cost</td>
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<td>$cc$</td>
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<td>Internal failure cost</td>
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**Table:** Technology characteristics

- Technical
  - Cutting velocity
  - Laser power
- Process-related
  - Productivity
  - Primary time
- Product-related
  - Material
  - Geometry
- Time-related
  - Productivity
  - Primary time
schemes exist. However, especially the monetary quantification of flexibility remains challenging. In this case, a toolbox approach for flexibility measurements is aspired since the measure of flexibility has to be adapted for diverse environments and situation specific. Subsequently, cost have to be linked with technology characteristics via cause and effect relationships. Although the description of some relationships do exist, it is necessary to define a general process for the derivation of such cause and effect relationships accompanied with supporting methods and an appropriate technology description. Moreover, the applicability of the model has to be evaluated in case studies.

4. Summary

A generic model to determine the value of a manufacturing technology in the context its deployment in a manufacturing systems is presented. The characteristics of the valuation model are summarized below:

- The value of a manufacturing technology heavily depends on the context of its application, i.e. the manufacturing system and its objectives.
- Existing valuation methods do not link technology-related objectives of the manufacturing system and technology characteristics.
- Hence, the proposed manufacturing technology valuation model aims at the determination of the value-contribution of an applied or future manufacturing technology to the manufacturing system.
- The monetary valuation model is based on the discounted cash flow approach. Revenues and cost categories are derived from technology-related manufacturing systems objectives.
- Structured revenue and cost factors and subcategories accompanied with cause and effect relationships to relevant technology characteristics shall be derived in this on-going research. A module-based technology description is aspired to compare diverse manufacturing technologies in a uniform manner.

The proposed monetary valuation model can help to eliminate the difficulty of complex interactions, conflicting objectives and different forms of data and information which are reflected by the number of different evaluation criteria in technology assessment. Hence, the presented model aims at the development of an innovative metrology, that can assist technology-oriented companies and technology managers in the valuation of applied or future technologies in a manufacturing system.

Acknowledgements

This research is supported by the German Research Foundation (Deutsche Forschungsgemeinschaft DFG). The authors gratefully acknowledge the financial support of the German Research Foundation within the project number SCHU 1495/43-1.

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